Assessment of Solar XXI Building Sustainability by SBTool^{PT} Methodology

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ABSTRACT: In this paper that focus on the building sector, it's presented the evaluation of the sustainable performance of an office building in Lisbon – Solar XXI. This analysis was performed using the SBTool^{PT} methodology, which is a methodology initially developed by (Mateus and Bragança 2006) at Minho's University, for application in residential buildings. This study confirmed not only the high performance of Solar XXI but also the flexibility and adaptability of SBTool^{PT} to different kinds of buildings, locations and cultural concepts.

1. INTROCUCTION:

1.1. *Sustainable construction*

Nowadays, the construction industry is one of the most active and dominant activities in the world, with a strong influence on its economy, society and environment. According to OECD (2003) this industry, in 2003, represented 9,7% of the GNP (gross national product) in Europe.

In Pinheiro (2006) is mentioned that the construction sector is responsible for 7% of the employment in the world, which may increase up to 23% in developing countries. In what concerns to environment, the construction industry contributes actively to its degradation through the dilapidation of natural resources, since it consumes 3000 Mt/year of raw materials, in the world (Torgal and Jalali 2007), 55% of the wood extractions for non-fuel purposes and 40% of stone, gravel and sand (Roodman and Lenssen 1995). It is also responsible for 40% of the primary energy annually consumed in the world as stated by Energy Efficiency in Buildings (2009) and responsible for 180 million tons per year of the waste produced in Europe (OECD 2003).

The main purpose of the construction sector is to provide buildings that are able to satisfy the owners' functional needs, given their budget and the design aspects. Combining these aspects and the actual way of life, the living conditions in the world will became unbearable.

Therefore, an improvement on the way of thinking and acting, especially in the construction sector, is essentially to achieve the sustainability.

Mateus and Bragança (2006) and Pinheiro (2006) cited Charles Kibert to apply the sustainable concept to the construction industry, "*Sustainable construction is the responsible development and management of a healthy built environment, based on the efficient use of the resources and on the ecological principles*". This concept integrates the eco-efficiency principles with the economic and social constrains, merging therefore the three dimensions: environment, society and economy.

The principles have to be applied during the entire life cycle of the building, such as: (a) minimizing the water consumption; (b) re-use resources when possible; (c) recycle materials; (d) protect the natural resources and their function in every activity related to them; (e) avoid the products and sub-products with high level of toxicity.

2. BUILDING CHARACTERIZATION

This study focus on the Solar XXI, which is an office building in Portugal headquarters to the Renewable Energy Department of LNEG, in Lisbon. This building, constructed between 2004 and 2005, intends to be an example of energy efficiency and self supporting energy, as it integrates the solar passive concepts of the bioclimatic design with the active ones, looking forward to reduce its own need of heating and cooling (Gonçalves and Cabrito 2006).

The building has about 1500 square meters along its three floors, one of them lying underground in the South façade. The main occupied spaces, such as office rooms, are located on the south part of the building while the less occupied ones, as meeting rooms and laboratories, are in the north side.

The central part has a skylight that harnesses natural lighting for the three floors, as there are transparent elements between the central corridor and adjacent rooms (CEETA and Keep Cool). Moreover, it is possible to transfer heat from the southern to the northern side of the building due to the existing openings in the internal doors, by natural convection. Planned to maximize the solar gains during winter and minimize them during summer, Solar XXI has an entire façade turned south, which has a high area of double glazing with external movable venetian blinds.

The envelope of the building is external insulated with 5cm thick of EPS (expanded polystyrene) in a single masonry wall and has 10 cm insulation on the roof (5cm of EPS + 5cm XPS (extruded polystyrene)) (Gonçalves et al. 2008). These measures contribute to reduce the heat gains through opaque façades, helps on the heat storage in the mass of the building and its releasing during the night to indoor spaces. In addition, the building has a solar thermal system, located on the rooftop, consisting in eight collectors which fill up 15 square meters of reception area. Their efficiency is about 70% and they have a loose of 3.4 W/m2·K. In cooler days, this system assists the auxiliary heating system (boiler and radiators). The solar thermal system is also used in sanitary hot water preparation. In order to construct a building without air conditioning, Solar XXI has as main strategies for air cooling the prevention of solar gains, the night ventilation and a buried earth tubes. These last ones consist in a set of 32 concrete buried pipes at 4.6m depth, with 30cm of diameter each, allowing the air to flow from the inlet outside the building – 15m from the South façade – to the inside. The atmosphere air is cooled to the underground's temperature (≈ 16ºC) entering in the basement of the building and going up to the next floors. There are two incomings of fresh air in each south room which can be controlled individually by the inhabitants. The north rooms are less problematic in what regards the solar heat gains, and the cooling is obtained through natural ventilation.

At last, but not least, it is integrated in the building two Photovoltaic (PV) Systems, one in the South façade and the other on the car parking, to produce energy for own consumption. On the South envelope the PVs are located vertically reaching an area of 96 square meters (12 kWp) and providing around 12 MWh per year (Gonçalves et al. 2008). It's important to refer that due to the way that these PVs are installed it is possible to recover some heat produced by them in order to be used on the building's heating process. The PV system on the car parking has 6kWp and covers an area of 95 square meters. The two systems together correspond to approximately 76% of the electric energy required by the building's.

3. METHODOLOGY

Due to the significant changes needed to mitigate the environmental impact of building sector, progress has been made to amplify the building's sustainability. Diverse countries tried to develop several assessment tools to evaluate the sustainability performance of the constructions. They vary to a great extent as different phases of a building life cycle, different application scales (global, national, local, etc.) or even different issues taken into account (Haapio and Viitaniemi 2008). Erlandsson and Borg (2003) refer that the majority of tools is developed based on a bottom up principle; this means, the sum of individual performances of the buildings' compounds is equal to the global performance of the building. However, Allecker and DeTroyer (2006) said it is not right to consider the building as the sum of its compounds, because of the design influence on the global impacts. Therefore, it is possible to classify several methodologies by types although there are different opinions in how to do it. Mateus and Bragança (2006) support the division made by the *ATHENA Institute* (Trusty 2000), dividing the methodologies into three categories: (1) whole building design or decision support tools, such as ATHENA^{TM}, BEAT 2000; (2) product comparison tools and information sources, as BEES and TEAM^{TM}; (3) whole building assessment frameworks or systems, as LEED, BREEAM and SBTool. The third group integrates systems and tools that recognize the sustainable construction, during the whole phases of building's life cycle. Therefore within this group a better integration of the three sustainability dimensions is achieved. Although there are different methodologies in this group, all of them analyze the following categories:

- Site selection and planning;
- Energy consumption and its sources;
- Environmental load (water, residues, exterior air quality);
- Inside air quality;
- Functionality (noise, comfort, lighting).

This paper focuses on the study using SBTool (Sustainable Building Tool) which can be found in this last group of methodologies. The development of this tool involved the joint effort of several countries, since 1996 and it was promoted by the International Initiative for a Sustainable Built Environment (iiSBE) (Pinheiro 2006). This international involvement supported its distinction among the others methodologies, since SBTool was designed to allow users to reflect different priorities, technologies and building and cultural traditions in the same methodology. Therefore, SBTool has a global structure; it is adjustable to each country or region providing approximate assessments of a broad of potential environmental performance parameters, all of them related to the performance of benchmarks that are relevant to the region and building type of occupancy.

The Portuguese version of SBTool was developed by the University of Minho in Portugal. This methodology approaches the three dimensions of the sustainable concept: environment, society and economy. In SBToolPT the evaluation is accomplished relatively to the most applied solution in a certain place. The framework of this methodology follows the five steps listed below as stated by Bragança et al. (2007):

- Definition of system boundaries;
- Definition of parameters;
- Quantification of parameters;
- Normalization and aggregation of parameters;
- Sustainable score calculation and evaluation.

3.1. *Definition of system boundaries*

Although, the SBTool^{PT} was at first developed to assess residential buildings, in this study it is applied to office buildings. The object of the evaluation is the building, its foundations and external works in the building site (Bragança et al. 2007). Issues as the urban impact in the surroundings, the construction of communication, energy and transport networks are excluded. Regarding the temporal boundary, it should be the whole life cycle (*from cradle to grave*) for new buildings. For the ones that are already constructed the temporal boundary stars from the moment of the intervention to the final disposal. It is also necessary to define the daily hours of occupation and the occupation density.

3.2. *Definition of parameters*

Being holistic, the methodology cannot assess all the parameters involved on the constructive solution. Thus, there is the need to select the parameters to include in the assessment, setting up their quantity and type. Parameters that are able to raise complexity and subjectivity to the evaluation should be excluded.

The environmental parameters choice was based on the work carried out by the CEN/TC 350 WG1. The environmental performance was assessed by the quantification of the potential effects connected to the materials and technologies used during the building's construction. Although SBToolPT has initially included fifteen parameters distributed in five categories, this assessment evaluated fourteen parameters in the following five categories:

- C1 – Climate change and outdoor air quality (ex.: overall index of environmental impact categories of the building's life cycle);
- C2 – Biodiversity and land use (ex.: percentage of plan area with reflectance equal or greater than 60%);
- C3 – Energy (ex.: consumption of non-renewable primary energy during the occupation phase and quantity of renewable energy produced in the building);
- C4 – Materials and solid waste (ex.: percentage of building's recycled content and building's potential to promote waste separation);
- C5 – Water (ex.: annual consumption per capita, and potential to re-use wastewater).

In the social performance analysis there were only included parameters related to heath and comfort of the inhabitants, distributed in two categories:

- C6 – Comfort and Health of occupants (ex.: thermal and visual comfort, natural ventilation potential and toxicity of the finishing materials);
- C7 – Accessibility (ex.: access to public transports and amenities.

The acoustic comfort was not included because the acoustic project was not available and there was no time to perform resulting tests.

Lastly, the economic performance includes all the costs related to the whole building's life-cycle, however the presented case study only included the occupation costs, because the information need to evaluate the initial cost was not available;

- C9 – Life cycle cost (occupation cost per square meter).

3.3. *Quantification of parameters*

After selecting the parameters it's necessary to proceed with their quantification, which allows the comparison between the solution under study and the benchmarking solutions. As there are several parameters under study and each one has its own way of quantification, it is impossible to describe all of the procedures executed during the assessment. The environmental parameters quantification followed the bibliography Berge (2001), where it is possible to find data about potential sources of buildings' environmental impact. For the quantification of the social parameters, there were used several normalized methodologies available regarding also the national law, in some cases. The last group of parameters, the economic ones, was quantified using the LCCA (life cycle cost analysis) procedures.

3.4. *Normalization and aggregation of parameters*

The normalization aims the extinction of scale effects in the aggregation phase and was achieved applying the Díaz-Balteiro and Romero (2004) equation:

$$\overline{P_i} = \frac{P_i - P_{i*}}{P_i^* - P_{i*}} \quad \forall i \qquad (1)$$

Where Pi is the value of the ith parameter, Pi* is the best value of the ith parameter and Pi* is the standard value for the same sustainable parameters.

This procedure make the parameters values dimensionless, within a scale 0 (worst value) to 1 (best value), facilitating the aggregation and the comparison with benchmarks.

The aggregation consists on a weighted merge of the parameters into categories and the categories into dimensions in order to obtain three single indicators. These three values are obtained using the equation (2) which final result gives the dimension performance.

$$I_j = \sum_{i=1}^{n} w_i \times \overline{P_i} \qquad (2)$$

Where Ij is the weighted average of all normalized parameters $\overline{P_i}$ from the indicator j, wi is the weight of the parameter ith.

This weighting average process may not be consensus and can suffer changes depending on specific situations. The weights used on the environmental performance have international acceptance due to the United States Environmental Protection Agency (EPA) studies, which give the relative importance of each parameter according to its harmful effect on the environment (Bragança et al. 2007). The evaluation of social parameters is easy however there are some discussions, caused by disagreement on the influence of each parameter on the final result. As so, to avoid this subjectivity, it is left out of the assessment all parameters that are not directly related to health and comfort of the building's occupants.

3.5. *Sustainable score determination and evaluation*

The assessment ends with the quantification of the sustainable score (SS). The SS is a single index that represents the global sustainability performance of the building, and it is achieved by using the equation (3).

$$SS = w_{G1} \cdot I_A + w_{G2} \cdot I_S + w_{G3} \cdot I_E \tag{3}$$

Where SS is the sustainability score, Ii is the indicator of the dimension i and wj is the weight of the indicator jth.

The evaluation of the SS is still not consensual, since it is obtain through the use of weighting factors. In this study the environmental dimension had a high importance while social and economic dimensions shared the same weighting value, Table 1.

Table 1. Weight of each sustainable dimension in the SS.

Dimension	Weight (%)
Environment	40
Social	30
Economic	30

The assessment only finishes after the qualitatively classification (Table 2) of the SS and the emission of a sustainable certificate.

Table 2. Levels and conditions to the assessment of the three sustainable dimensions and its indicators.

Level	Condition	Level	Condition
A$^+$	$\overline{P_i} > 1.00$	D	$0.30 < \overline{P_i} \leq 0.50$
A	$0.90 < \overline{P_i} \leq 1.00$	E	$0.10 < \overline{P_i} \leq 0.30$
B	$0.70 < \overline{P_i} \leq 0.90$	F	$0.00 < \overline{P_i} \leq 0.10$
C	$0.50 < \overline{P_i} \leq 0.70$	G	$\overline{P_i} < 0,00$

Where $\overline{P_i}$ represents the parameter i^{th} or the SS.

In spite of the need to determinate in which level fits the SS, this global index should not be presented alone, since the values' aggregation may hide some significant differences between the indicators values. There for it is important to display also the intermediate indicators.

4. RESULTS

In order to facilitate the understanding, this section follows the framework of the SBTool^{PT} methodology.

4.1. *Definition of system boundaries*

As the assessed building is an office building it was necessary to follow the Portuguese law for this type of building – *Regulamento dos Sistemas Energéticos e Climatização de Edifícios (RSECE, 2006)*. According to *RSECE*, Solar XXI is similar to an office building with 14 hours of use per day and it's closed during the weekend. The occupation density was established in 30 square meters per occupant (approx. 50 occupants). From the whole life-cycle of the building there were only assessed the phases of construction and occupancy.

4.2. *Performance evaluation*

4.2.1.Environmental performance

Table 3 resumes the results of the categories assessed on the environmental dimension (D1). Each category has its own parameters performances.

Table 3. Resume of environmental parameters evaluation.

Category	Parameter	P. value	P. value (Normalized)	P. Weighing Factor (%)	P. Weighted Value	P. Performance
C1	P1	-.-	1.3	100	1.3	A^+
C2	P3	49.03 %	0.35	8.06	0.03	D
	P4	100 %	1.11	9.68	0.11	A^+
	P5	51.73 %	0.84	38.71	0.33	B
	P6	80.27 %	0.23	43.55	0.10	E
C3	P7	31 kgep/m^2.year	1.0	50.0	0.5	A
	P8	6406.04 kgep/year	0.26	50.0	0.13	C
C4	P9	2.03 %	0.14	25.0	0.03	E
	P10	262 ton	0.6	25.0	0.25	E
	P11	23.16 %	4.63	28	1.30	A^+
	P12	0.0 %	0.0	18.0	0.0	G
	P13	40 %	0.75	40.0	0.30	B
C5	P14	9.13 m^3/occupant	0.99	64	0.637	A
	P15	0.0 %	0	36	0.0	G

The C1 accounted only the construction phase. So, there were evaluated all the materials and construction solutions used on Solar XXI and their areas, for all the construction elements (walls, floor, etc.) in the following categories: Global warming potential (GWP); Ozone depletion potential (ODP); Acidification potential (AP); Photochemical ozone creation potential (POCP); Eutrophication potential (EP) and Fossil fuel depletion potential (FFDP).

The C2 was accomplished with the evaluation of four parameters: Land waterproofing index (P3); Percentage of used land previously contaminated or built (P4); Percentage of green areas reserved to native plants (P5); Percentage of plan area with reflectance equal or greater than 60% (P6). Each one had a different method of quantification due to their specifications. The third category, C3, evaluated the consumption of non-renewable primary energy during the occupation phase (P7) and quantity of renewable energy produced in the building (P8). Unlike it was expected, this assessment did not confirm the building's energy efficiency. It was expected a class A+ performance given the characteristics of Solar XXI and its known evidences of energy efficiency. The result was a class C performance, probably due to some undisclosed information at the moment. The evaluation of the C4 accounted five parameters: Cost percentage of re-used materials (P9); Weight percentage of building's recycled content (P10); Cost percentage of certificated organic based products (P11); Mass percentage of substitute materials of cement in concrete (P12); Building's potential to promote waste separation (P13). The water category, C5, showed that Solar XXI has a great potential in re-using wastewater as it has no facilities installed to execute this issue (P15). The final result also proved a small amount of water consumption (P14).

4.2.2.Social performance

Table 4 lists the results obtained in the social performance (D2) quantification.

Table 4. Resume of social parameters evaluation.

Category	Parameter	P. value	P. Value (Normalized)	P. Weighing Factor (%)	P.Weighted Value	P. Performance
C6	P16	80 credits	1.67	12.35	0.21	A^+
	P17	99.63 %	1.11	17.28	0.19	A^+
	P18	-. -	0.99	39.51	0.39	A^+
	P19	-. -	2.92	30.86	0.90	A^+
C7	P21	6.0	0.33	55.0	0.18	D
	P22	55	2.7	45.0	1.2	A^+

The C6 as it was said before did not evaluate the acoustic comfort. All the other parameters assessed a class A+ performance, as expected; the ventilation potential (P16), the weighted percentage of finishing materials with low amount of VOC (volatile organic compounds) (P17), the annual average of thermal comfort (P18) and the average of daylight factor (P19). The P18 was not evaluated with the initial proposed values because there wasn´t enough information available, however it was assessed using the values presented on the Gonçalves et al. (2008) paper. The C7 assessment was carried out by the calculation of two parameters: the accessibility to public transports (P21) and to amenities (P22). Despite the good result of P22, the access to public transports obtained an unexpected result to a city as Lisbon. The C8 category – education to sustainability – was not included since the values needed were not available to this office building.

4.2.3.Economic performance

Table 5 shows the results from the unique parameter evaluated on the economic performance (D3), which obtain a good result, class A performance.

Table 5. Resume of economical parameter evaluation.

Category	Parameter	P. value	P. value (normalized)	P. Weighing Factor (%)	P. Weighted Value	P. Performance
C9	P25	20.35 €/m^2.year	0.99	100	0.99	A

4.3. *Sustainability Score Determination*

The table 6 resumes the aggregation process, and shows its final results. Each dimension obtained a very good result: D1 – class A; D2 – class A^+ and D3 – class A. The aggregation of this three values, gave the SS value, which showed that Solar XXI has a class A^+ Sustainable Performance. Moreover, with this result it was possible to emit a Sustainability Certificate to Solar XXI, by the SBTool^{PT} methodology.

Table 6. Category aggregation and SS determination.

Dimension		C. performance	C. Weighing Factor (%)	C. Weighted value	D. performance	SS
D1	C1	1.33	12.0	0.16	0.94 ⇒ A	
	C2	0.56	0.19	0.11		
	C3	0.63	0.39	0.25		
	C4	1.69	0.22	0.37		
	C5	0.64	0.08	0.05		1.15 ⇒ A+
D2	C6	1.69	0.69	1.16	1.59 ⇒ A^+	
	C7	1.38	0.31	0.43		
D3	C9	0.99	100	0.99	0.99 ⇒ A	

5. CONCLUSIONS

Globally, the necessity to think forward on sustainable construction is essential to improve the world and the life of its habitants.

Sustainable design, construction, operation, disposal and refurnishing of buildings should be base on the environmental pressure, social impact and life-cycle costs, otherwise, the rupture of natural resources, comfort and economic systems will be unavoidable.

This paper presents the evaluation of the sustainable performance of the office building - Solar XXI, using the SBToolPT methodology. Although SBToolPT has been specifically developed to residential buildings, in this study it was applied to an office building, testing and proving its flexibility and capability of adapting itself to the particular features of the studied building.

During this evaluation there was a need to readjust some of the parameters and, in certain cases, some were completely excluded. However, the final result was positive, as it was verified that beyond being energetically efficient, the Solar XXI represents a good example in how to achieve the sustainability in the construction sector.

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